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The effects of gaps between bridge foils and PETN as a function of PETN density and specific surface area

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ABSTRACT

X-ray computer tomography scans of artificially aged PETN seem to indicate shrinkage of material and, by extension, an increased high explosive density, resulting in potential separation of the HE from the header/bridge foil. We have investigated these phenomena by mimicking this shrinkage of material (load density). Thus, we have evaluated various induced gaps between the exploding bridge foil and the PETN in our custom detonators by changing both specific surface area – recognizing crystal morphology changes – and load density.

Analyses for these data include absolute function time relative to bridge burst and careful evaluation of the detonation wave breakout curvature, using an electronic streak camera for wave capture, in cases where the bridge foil (exploding bridge wire – EBW style) initiation successfully traverses the gap (a "go" condition). In addition, a fireset with sub-nanosecond trigger jitter was used for these tests allowing easy comparison of relative "go" function times. Using the same test matrix and fine-tuning the induced gap, a second, smaller subset of these experiments were performed to provide additional insight as to what conditions we might expect detonator anomalies/failure.

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1. INTRODUCTION

We performed a series of tests using custom built detonators (fig. 1) loaded with two different surface area PETNs and two different densities. The densities chosen were approximately 6% apart – simulating what we believe might be representative of the aging/densification/sintering process that PETN is subject to over time. We then carefully introduced gaps between the exploding bridge foil and the PETN immediately before each firing.

Our custom detonators were loaded at Teledyne RISI Inc, a company in the business of producing commercially available detonators for industry. All parts involved with detonator construction – including the PETN – were delivered to RISI and, under our direct supervision, were loaded with exact weights into known volumes. The detonators were pressed to a stop using the same machine and operator. Each detonator was then capped with a glass plug coated with 1500 angstroms of aluminum (the aluminum side of the plug placed in intimate contact with the PETN) to provide clear pictures of the detonation wave which was then optically relayed and captured on an electronic streak camera. The use of aluminum under these circumstances provides an optical (light) "hold-off" of sorts – not allowing light generated from the detonation wave to transmit until the wave front burns away the aluminum (Roeske et. al [1]). These detonators were designed to have a coupling nut that could be unscrewed and shims installed into a predefined space to set the gaps at 0 mil, 2 mil, 3 mil, 4 mil, and 6 mil. "2 mil" or 0.002 inches is equivalent to 50.8 µm. The alignment collar, holding the ceramic substrate/bridge foil (right side fig. 1.), could then be accurately pulled back from the PETN. Because we individually evaluated and adjusted each detonator body, we were able to rely on a friction fit between the alignment collar and the brass body - maintaining our introduced gap for the few minutes before each detonation. Each bridge foil is 9 µm thick. Care was taken while separating the foil header from the HE to ensure we not rotate the header with respect to the HE. Given our minimum gap of 2 mils, we recognized the thickness of the bridge foil equates to 18% of the gap (at 2 mils).

2. EXPERIMENT CONFIGURATION

The experiment test configuration consisted of positioning the detonator vertically and optically relaying light from the detonation wave over to the electronic streak camera (fig. 2 and fig. 3). We also calculated and graphed timing loop closures for absolute detonator function time. The loop closure process involves cross-timing one known event (bridge wire burst) on two or more event recording devices. In our case, a bridge burst was recorded on both the electronic streak camera (light from the bursting bridge) and a digitizing oscilloscope via a voltage probe (indicating exact burst timing) connected directly to the fireset. Once the loop closure is evaluated for a common event, it is then a simple process to incorporate actual shot (HE) timing information and determine detonator function time. Measurements were also made from collected oscilloscope data evaluating function times of the bridge foil burst. This measurement seemed to indicate some variation of function time of the bridges– on the order of 10's of nanoseconds. However, because we individually evaluated each detonator timing loop closure, we accounted for any of this variation in function of each detonator's exploding bridge foil. The fireset was selected for its ability to deliver 650 amps across the bridge foil. Foil dimensions are 0.63 mm long by 0.12 mm wide by 9µm thick.

2. EXPERIMENT RESULTS

Raw data captured by the electronic streak camera is shown in figure 4. Each photo shows a timing mark (the single dot on the left side of each), the detonation wave itself, and an optical comb (the column of dots on the right) representing 25 nanoseconds between each dot.

Imagine time beginning at the top of each photo and traveling toward the bottom of the page. The photo on the right – with the 0.004 inch gap (4 mil) - does, in fact, arrive later in relation to the single optical mark (the same point in time for both photos) on the left side of each picture. The single, narrow, dark vertical line running through each detonation wave (near the peak) is an anomaly of the photo cathode tube in the streak camera. It can be ignored.

Nearly 80 shots were fired in the PETN gap series. Data presented in figure 5 represents the two primary PETNs tested. PETN with a specific surface area (SSA) of 4500 cm^2/gm shown on the left and PETN with a specific surface area of 6500 cm^2/gm on the right. We made an effort to fire a minimum of 3 shots at each configuration – accounting for density, surface area, and the gap conditions – to provide some statistical results. It should be noted that the detonators were designed in such a way as to minimize any possible *increase* in stated and tested gap. On the other hand, it was possible for any given detonator to have *less* than the stated tested gap. In other words, it was mechanically possible to have attempted to set the detonator under test for a 6 mil gap and have only actually achieved a 4 or, perhaps 5 mil gap. Reviewing figure 5, it is apparent there are several data points for both surface area PETNs that appear to function near the "0 gap" function time. It is certainly possible the tested detonator gap collapsed just prior to the test. The PETN gap experiments were conducted in two primary data collection sets and several months apart. It became evident, after preliminary tests, that we'd like some additional data at the "knee" area (3 mil) of where we were seeing some significant function time changes and/or a "NOGO" condition. The 3 mil gaps were added specifically to provide additional insight into just how large a gap might be tolerated before failure. Looking at the right side of figure 5, one will see that the function times for the higher SSA PETN seem to function approximately 200 nanoseconds sooner than those on the left. Density, of course, also contributes to function time and is roughly proportional between the two PETNs. Within a PETN type, at 0 mil gap, density appears to contribute a bit less than 100 nanoseconds (average) difference.

Upon closer inspection of the data on the right of figure 5, four data points can be seen in the lower left. These data points represent shots fired after loading with an increased density (1.05 g/cm^3, an increase of approximately 6%) with no gap and were included to verify a continuing, reduced function time as a result of higher load density. Their average function times, as shown on the graph, are proportionally shorter.

In addition to analyzing detonator function time, we also spent considerable effort studying the curvature of the detonation wave as captured on the electronic streak camera. Figure 6 shows what we believe to be a couple of extreme examples – namely, the comparison of detonation curve data between a 0 mil gap with a captured 6 mil gap *within a PETN type and density*. The left side shows SSA 4500 PETN and the right shows SSA 6500. It became evident that there wasn't significant difference between the detonation profiles after performing several hand digitizations of the detonation curves, applying a 4^{th} order polynomial curve fit and then comparing those curve fits with each other. There is no apparent trend in detonation wave characteristics within either SSA PETN nor are there any trends based on gap. One interesting thing to note, however, is the "hiccup" occasionally seen at the ends of the detonation curves of only the SSA 6500 data (right side fig. 5). We have not identified exactly what might cause this anomaly. However, we suspect a density gradient (Lee [2]) was produced while pressing the high explosives.

3. EXPERIMENT SUMMATION and CONCLUSIONS

A summation of data is represented in table 1. We can say that detonators without gap – or with a very small gap (2 mils) – appear to function as we might expect. Detonators with *any* tested gap larger than 2mils appear to be at risk for late function time or a NOGO condition. Both the SSA 4500 and SSA 6500 seem to demonstrate late function times or NOGOs. Higher explosive density produces faster detonation waves and apparent detonator function times (Hornig et al. [3]). Viewing figure 5, a case might be made that higher load densities – especially for the lower surface area PETN – appear to indicate more dramatic GO/NOGO conditions (ie. little *delayed* function time….either a GO or a NOGO). Without question, however, more tests would be needed to confirm this possibility.

K1202-6600 High surface	6500 High surface	Pantex- 4500 Low surface
NO gap - 0.93 * - **GO**	NO gap - 0.93 ** - **GO**	NO gap - 0.93 ** - **GO**
NO gap - 0.93 * - **GO**	NO gap - 0.99 ** - **GO**	NO gap - 0.99 ** - **GO**
	NO gap - 1.05 ** - **GO**	
	2mil gap - 0.93 ** - **GO**	2mil gap - 0.93 ** - **GO**
	2mil gap - 0.99 ** - **GO**	2mil gap - 0.99 ** - **GO**
	3mil gap - 0.93 ** - **GO/NOGO**	3mil gap - 0.93 ** -**GO/GOLATE**
	3mil gap - 0.99 ** - **GO**	3mil gap - 0.99 ** - **GO**
	4mil gap - 0.93 ** - **GO/NOGO**	4mil gap - 0.93 ** - **GO/NOGO**
	4mil gap - 0.99 ** - **GO**	4mil gap - 0.99 ** - **GO/NOGO**
	6mil gap - 0.93 * -**GOWAYLATE**	6mil gap - 0.93 ** - **GO/NOGO**
	6mil gap - 0.99 ** - **NOGO**	6mil gap - 0.99 ** - **GO/NOGO**

Table 1. Summary of the types of PETN crystal surface areas, densities, gaps, and GO/NOGO results. Note the late action/NOGO indicated at gaps of 3 mil and larger.

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4. FIGURES and PICTURES

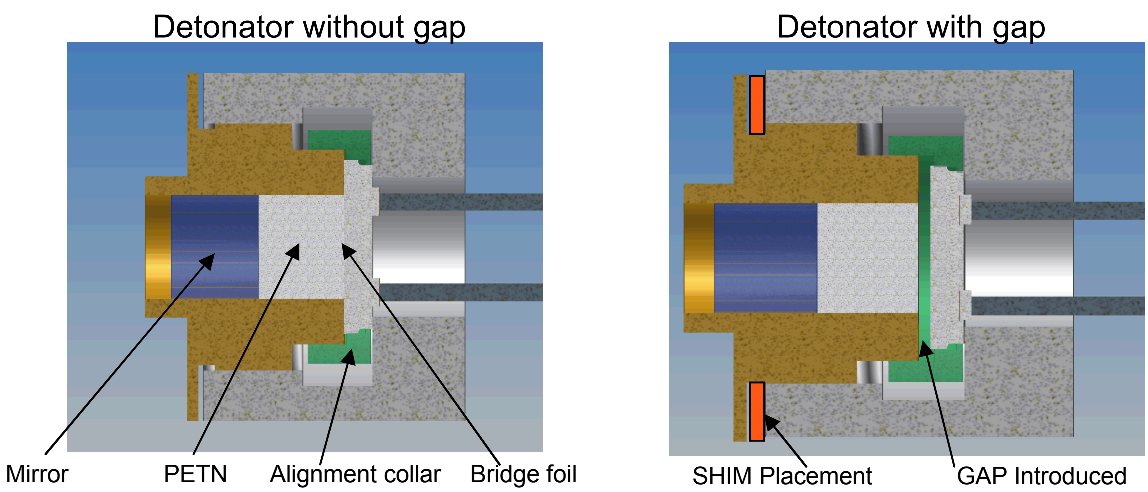


Figure 1. PETNgap custom detonators. Shown on the right is a detonator with the gap and shims introduced.

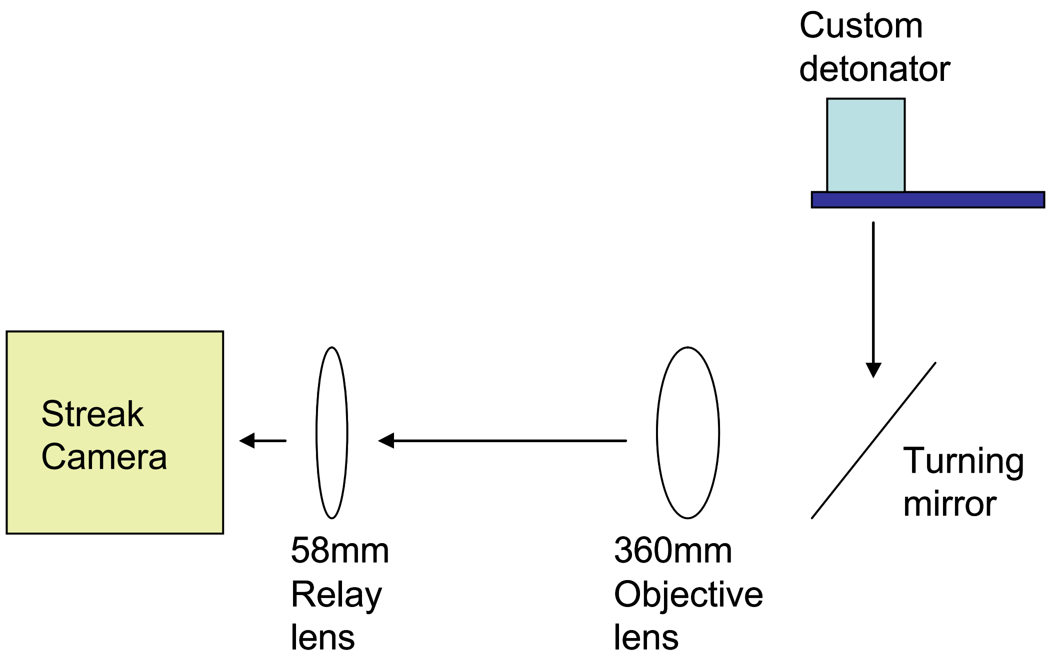


Figure 2. Diagram of experimental setup. The detonator explodes and light, representing the detonation wave, hits the turning mirror and is optically relayed to the streak camera.

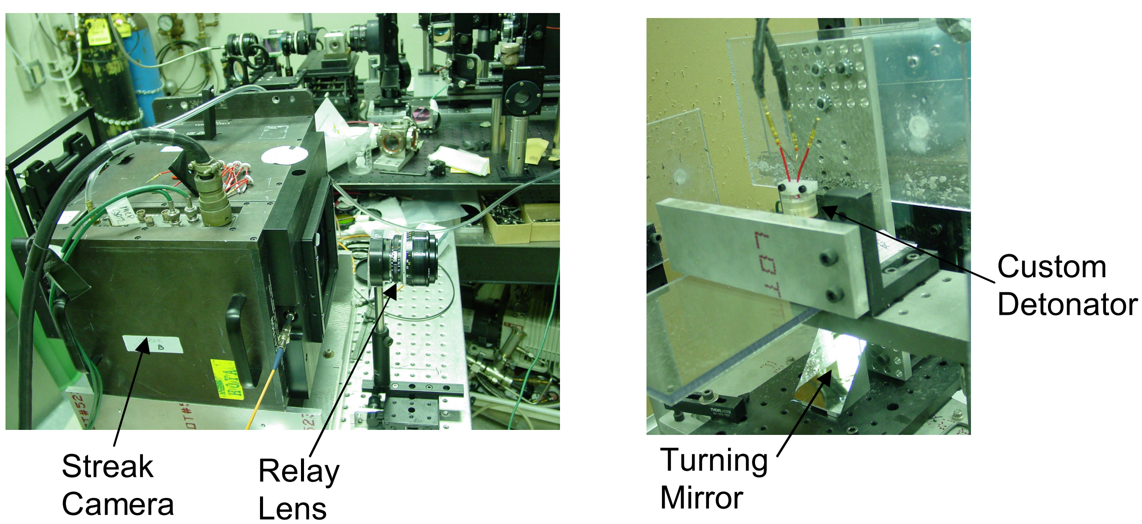
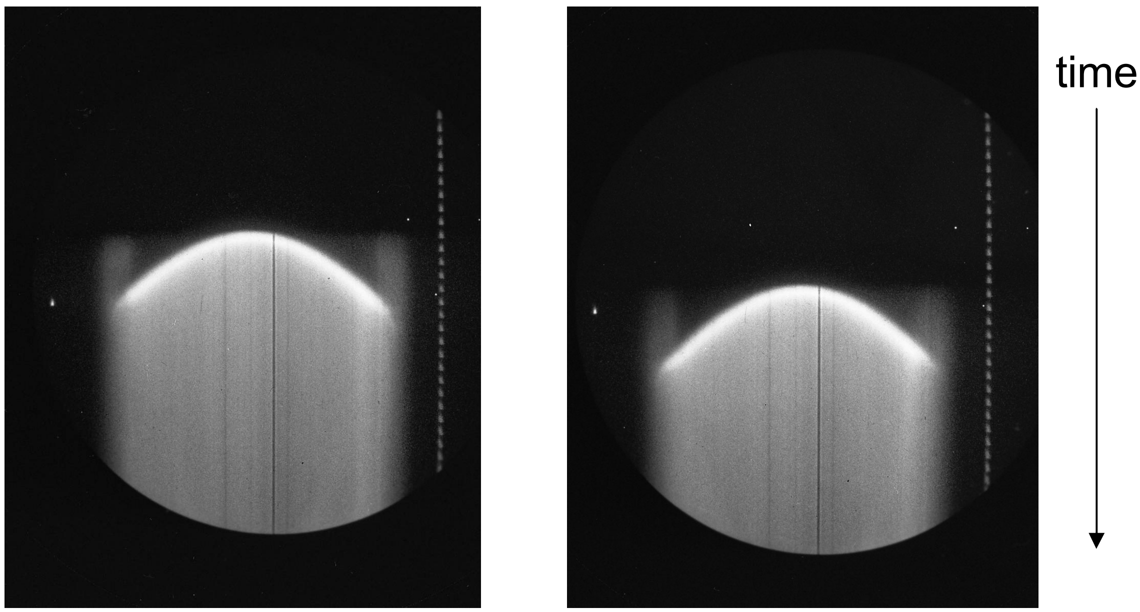


Figure 3. Photo of experimental setup. An electronic streak is used to capture the detonation wave – via image relay optics.



PETN	PETN
~ 4500 cm^2/gram	~ 4500 cm^2/gram
@ .002 inch gap*	@ .004 inch gap*

*all other cables and system timing - static

Figure 4. Raw streak camera data. A timing mark can be seen on the left side of each image. Time begins at the top. On the right of each photo, is the comb generator with each dot representing 25 nanoseconds. The right photo shows evidence of function time delay.

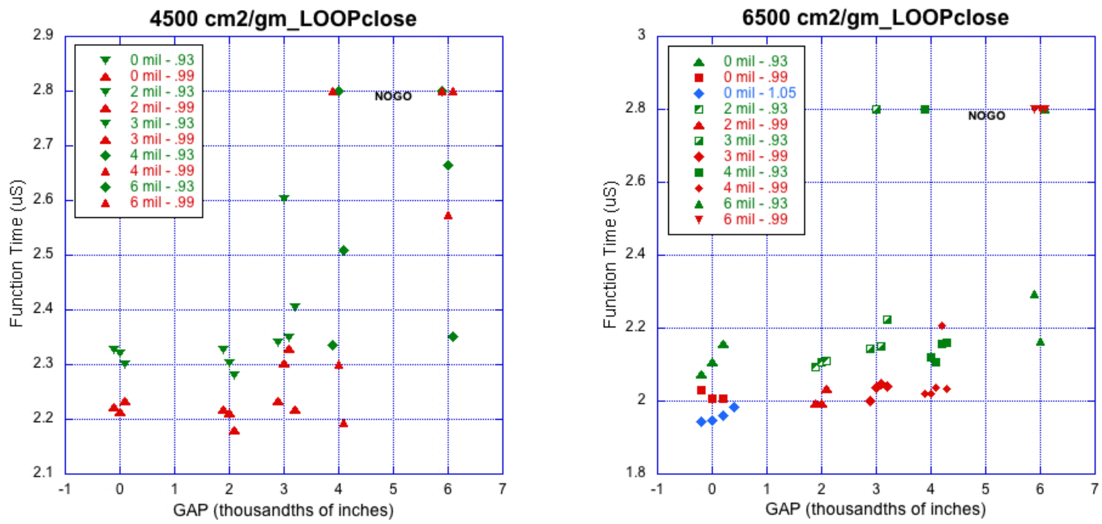


Figure 5. Function times for SSA4500 and SSA6500 PETN. It should be noted that the apparent separation (x-axis) of data points at the various gaps is artificial. In addition, near the top of each plot, at the "2.8" level, the "NOGO" (infinite function time) level was set. This is done for visual clarity.

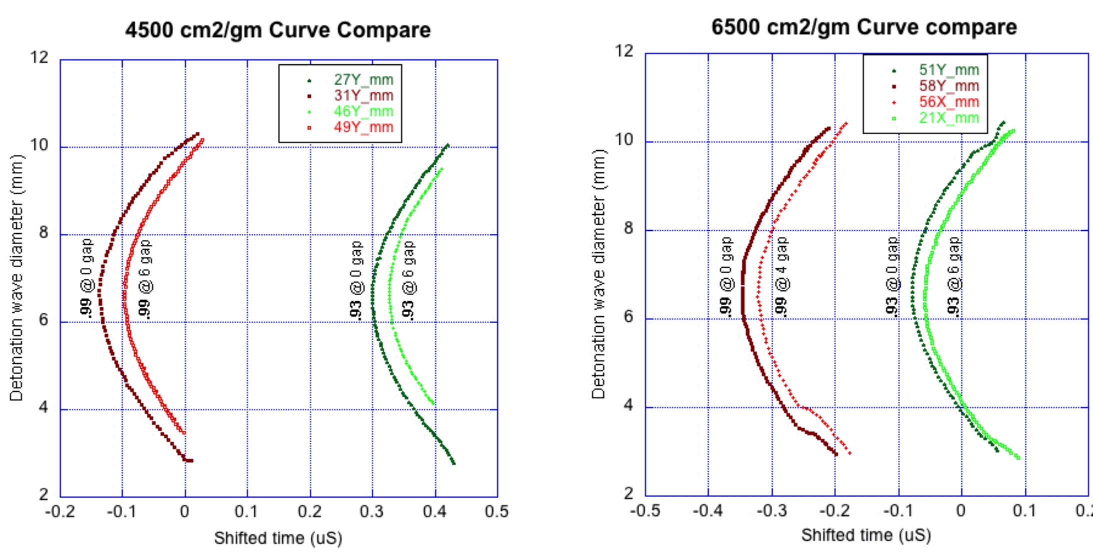


Figure 6. Comparison of hand-digitized detonation waves for the extremes of the gaps between the two surface areas and two densities. Note the wave anomaly at the edges of the higher surface area (6500) PETN… perhaps caused by pressing density gradients?

5. ACKNOWLEDGMENTS

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6. REFERENCES

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